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Slalom Water Skiing: Physiological Considerations and Specific Conditioning

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summary

This article discusses the unique biomechanical and metabolic demands of slalom water skiing, as well as important considerations for sport-specific training and prehabilitation.

Introduction

To the spectator, elite-level slalom water skiing may look like an effortless aquatic joyride. For the skier, however, a successful pass through a slalom course requires an intricate blend of technique, timing, strength, muscular coordination, and dynamic balance. This article will review the unique biomechanical and physiological demands of slalom water skiing and will make several recommendations for injury prevention and sport-specific training.

Slalom water ski courses comprise 6 fixed buoys, 3 positioned 11.5 m (37.7 ft) to the right of a centerline and 3 to the left (see Figure 1) (41). Two additional rows of buoys, 2.1 m (6.9 ft) apart, sandwich the centerline and delineate the path through which the boat must travel. Skiers enter the course through a pair of buoys constituting the entrance gate, maneuver their skis around the outsides of all 6 turn buoys, and exit the course through a final pair of exit buoys. In competition, athletes ski in rotation and, if they complete a successful pass, advance to successive rounds. With each new round, the towrope is shortened, increasing the difficulty of rounding the buoys. As rope lengths shorten, both the skiers' paths behind the boat and their lean toward the water's surface must become more angular, intensifying the challenges to balance and stability (see Figure 2). The winner is the skier who successfully negotiates the most buoys in the final round. Occasionally, competitions may be run in match-play format, in which one skier must simply outperform another in head-to-head fashion.

Rope lengths range from 18.3 m (60 ft) for novices to almost half that for world-class skiers. The current world records for men and women have been set at rope lengths of 9.75 m (32 ft) and 10.25 m (33.6 ft), respectively (40). Note that merely to reach the turn buoys using these rope lengths, the body must be almost completely extended and that shorter individuals may never be able to beat these records, regardless of skill.

To add still more to the challenge, boat speeds increase with skier ability, ranging from 26–28 mph (42–45 kph) for novices, to 34–36 mph (55–58 kph) for experts, with skiers actually accelerating to even faster speeds. At 36 mph (58 kph), a calibrated ski boat takes 16 seconds to travel straight through a regulation slalom course from entrance weather conditions, athletes living in regions with cold seasons are at a distinct disadvantage compared with those living in areas with warm weather yearround. Cold climates not only limit technique development to a few months per year, but also generate little overall support for the sport via ski enthusiasts, courses, competitions, and boat dealerships and repair facilities. In addition, short ski seasons may contribute to increased risks of injury by pressuring athletes to sidestep sound skill and conditioning progressions in efforts to make up for lost time.

Other barriers to accumulating quality ski time involve the day-to-day variability of weather and recreational boat traffic, the number of skiers training on a given course, and the expense of ski

to exit gates. Within this time, skiers must cover at least an additional 35 m (~115 ft) on a zigzag path, which requires alternately decelerating to 20–22 mph (32–35 kph) to round the buoys and accelerating to as fast as 70–80 mph (113–129 kph) (76) through the straightaways.

boat maintenance. Although certain environmental conditions, such as extreme cold, high winds, heavy rain, and electrical storms, impose obvious limitations on ski training (e.g., choppy water increases the difficulty of both skiing and boat driving), even mild winds and light boat traffic can thwart possibilities of peak performance. For this reason, many elite skiers train on private ski lakes, devoid of recreational boat traffic and landscaped to somewhat shield the wind. Others, however, must train on public waters and either contend with rough conditions or limit skiing to times when calm is more likely to prevail (usually early morning or twilight).

Most skiers, whether on public or private waters, must share access to a slalom course, which can profoundly impact

skiing is to slalom water ski. However, for several reasons, it is difficult for many to accumulate enough on-the-water training to realize their skiing potential. Most important, because quality ski individual ski time. In efforts to promote equitable ski time, courses generally have policies governing skier turn length and rotation (e.g., 1 turn = 6 passes,

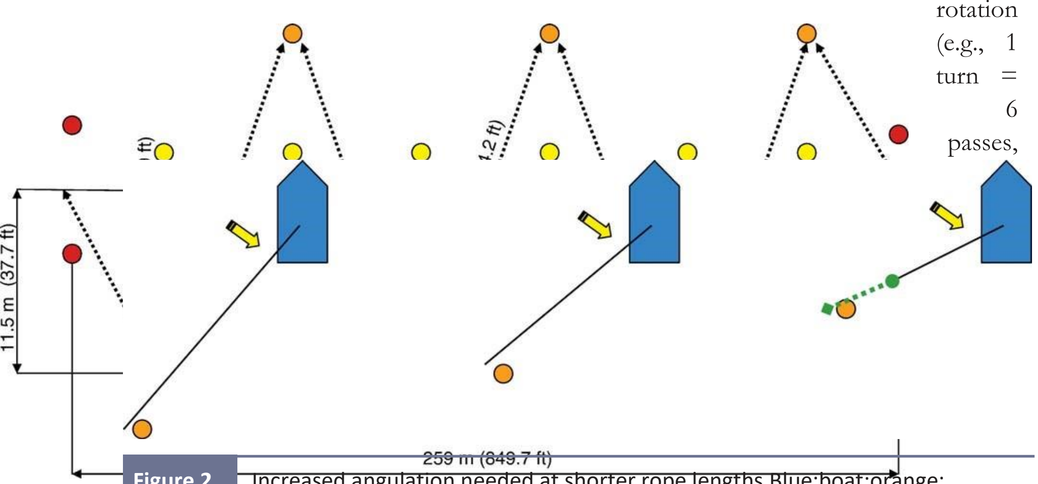

Figure 2. Increased angulation needed at shorter rope lengths.Blue:boat;orange: skier buoys; ----- :rope; ---- :skier

Figure 1. Major slalom course dimensions:Red:entrance and exit gates;yellow:boat guides;orange:skier buoys; ← and → :skier path.

3 falls, or 15

training depends on amenable water and equipment, course memberships, and

Rationale for Supplemental Training

It stands to reason that the best way to develop expert skills in slalom water

minutes, whichever comes first). Equitable, however, may be far from optimal. For example, sharing a course with 8 others on a given day would limit

individual ski time to about 15 minutes every 2 hours.

For all of these reasons, it is virtually impossible for many slalom water skiers to ski themselves into peak condition, thus making supplemental conditioning programs imperative. Program goals should center on developing and maintaining the neuromuscular characteristics consistent with sound slalom technique, prehabilitating the muscles and joints most vulnerable to injury, and correcting any musculoskeletal imbalances that stem from chronic ski training.

Biomechanical,Metabolic, and Injury Analyses

All sport-specific conditioning programs should be based on thorough biomechanical, metabolic, and injury analyses of the athletic event. Core considerations for optimizing program design include the primary muscle groups, types of muscle actions, joint ranges of motion, movement speeds, and energy system contributions required in the event, as well as common injury sites and mechanisms. These features, however, are more difficult to characterize for some events than for others, particularly for those that have been the subject of little scientific research, such as slalom water skiing.

Biomechanical Analysis

Biomechanically, slalom water skiing can be broken into the deep-water start and several repeating movements for skiing to and around each of the 6 turn buoys. The repeating movements of slalom skiing have been described previously by Eberhardt (20) and Leggett et al. (47) but will be reviewed and expanded upon for the purposes of this article. For the

two-footed, deepwater start, both feet are secured in tandem (heel to toe) in the ski

bindings, with the dominant foot forward. The skier assumes a crouched position in the water, with the front knee very near the chest, the ski angled approximately 45° away from vertical, and the ski tip protruding approximately 10–12 in. above the surface. The arms are extended, the handle held with a closed, alternated grip, and the rope positioned to the side of the ski opposite the front foot. As the boat begins to pull, the skier applies firm pressure to the ski with both feet, keeping the knees bent and shoulders back. Intense static action and dynamic balance are needed to prevent being pulled outside the very narrow, unstable base of support (BOS) while emerging to stand.

After emerging from the water, the skier travels to the far left of the boat wake to prepare for rightward acceleration through the entrance gate toward the first turn buoy. To initiate acceleration, the skier must forcefully pull the towrope handle toward the left hip, by retracting the scapulae, extending the shoulders, and first flexing, then extending the elbows to position the arms close by the sides. This movement requires forceful actions by the finger flexors to grip the handle; by the biceps and triceps brachii to flex and extend the elbows; by the trapezius, rhomboids, pectoralis minor, and rotator cuff musculature to retract, depress, and stabilize the scapulae; and by the latissimus dorsi, posterior deltoid, pectoralis major (sternal head), teres major, and triceps (long head) to extend the shoulder joint. Directing the handle toward the left hip causes counterrotation, or turning of the shoulders and hips toward the right. Counterrotation is critical to helping the skier shift the center of mass (COM) and put the ski on its right edge. A ski "on edge" cuts through the wake faster and with less bounce than a "flat" ski.

At the same time the skier initiates acceleration by pulling on the rope, the rest of the body must be positioned for maximum leverage against the boat. The head should be held in the neutral position, with eyes focused on the target buoy. The scapulae should be retracted, arms fairly extended, and handle pressed close to the body. The lumbar spine and hips should be extended as much as possible, with the knees and ankle flexed, so that the entire body leans away from the boat (Figure 3). Ankle position will vary according to the type of ski bindings used, individual flexibility, and changes in the angles of the hip and knee joints. The skier should strive to maintain this leveraged body position throughout much of the course, requiring strong actions by the erector spinae to extend the back, by the gluteus maximus and hamstrings to extend the hips, and by virtually all lower extremity musculature to appropriately manage the many forces acting on the body (e.g., drag, lift, buoyancy, tension, gravity).

Figure 3. The lean.

After pulling, accelerating, and leaning away from the boat, the skier must cross the wake, change edges of the ski (from right to left), decelerate, and arc around the first turn buoy. Edge change should occur somewhere between the center of the wake and shortly after crossing it, depending on skier ability and style, rope length, and boat speed. It results partly from conscious actions and partly from a natural pendulum effect of the rope pulling from the opposite direction (left). Conscious actions include standing slightly more erect and shifting the COM leftward by applying pressure to the handle, still held close to the hips.

After a successful edge change, the skier must precisely time the "reach" to initiate a tight turn around the outside of the buoy. Turning too early will result in missing the buoy on the inside, whereas turning too late will allow travel too far down course to make the next buoy. To initiate the reach, the skier releases the right (outside) hand and then extends the handle with the left smoothly toward the boat so as to maintain rope tension (Figure 4). This requires eccentric action by the shoulder extensors and strong fixation by the scapular stabilizers. The free arm should be controlled close to the waist, because allowing it to fly high in the air or behind the body could contribute to loss of balance. If proper body positions are maintained, the reach further shifts the COM to the left, causing considerable lateral body lean and redirection of the ski in the opposite direction. During the sideward lean, the quadratus lumborum is strongly activated, as indicated by the research of McGill et al. (55). If proper body positions are not maintained, any number of muscles and joints may be called upon to restore balance or to protect against damage during falls. For example, if the trunk is pulled forward into flexion, slack will appear in the rope and greatly reduce the likelihood of a successful pass. The forces exacted when slack lines pull taut can cause horrendous "out the front" crashes that greatly endanger ankle, knee, back, neck, and shoulder joints. Even when falls are avoided, they still can impose enough stress to cause injury.

Finally, at the apex of the turn, the skier must regrasp the handle with the free hand and once again pull forcefully toward the outside hip (right). This again initiates counterrotation and on-edge acceleration toward the next buoy, on the left side of the course. The skier who can complete this complex sequence 5 more times within 12–14 seconds can claim a successful pass.

Figure 4. The reach.

Because balance and joint positioning are challenged constantly by changing water conditions, driver performance, and repercussions of imperfect technique, a great deal of muscle coactivation and some degree of each type of muscle action—concentric, eccentric, and static—are needed to assume, to hold, and to resume proper body positioning. For example, a skier who pulls too forcefully on the handle may overaccelerate and will introduce slack into the rope. The subsequent uptake of that slack by the boat can result in a powerful, whip-like application of force to the skier. If this force (or the anticipation of it) does not completely fell the skier, it will at least likely cause some degree of shoulder girdle protraction, spine, hip, and shoulder flexion, and, depending on the skier's reaction, either knee extension or increased knee flexion. Accordingly, strong eccentric action by the muscles that counter these movements will be needed to resist the force and prevent falling. The trapezius and rhomboids will be called upon to resist scapular protraction; the rotator cuff musculature to resist glenohumeral distraction; the latissimus dorsi, teres major, posterior deltoid, and triceps brachii (long head) to resist shoulder flexion; the erector spinae to resist spinal flexion, the gluteus maximus and hamstrings to resist hip flexion; and either the hamstrings or the quadriceps to resist knee extension or flexion, respectively. The importance of such eccentric action to slalom skiing is evidenced by the superior knee extensor strength of professional water skiers (46).

No biomechanical analysis of a sport carried out entirely on such a narrow BOS as a slalom water ski (approximately 15–20 cm wide) would be complete without some discussion of balance, stability, and postural control. In general, "postural control" refers to the body's ability to attain, maintain, and restore balance during activity (66), especially upon exposure to forces that threaten it, including muscular action, gravity, friction, and ground reaction (63). "Balance," in turn, is recognized as the state present when all forces acting on a body are equal and oppositely directed (6), such that the body remains either at rest or at constant velocity. "Stability" refers to the ability to resist balance disruption and depends importantly on a body's BOS and COM, as well as friction or drag forces (34). In general, heavier bodies, with lower COMs and large BOSs, encountering high friction or drag forces, have greater stability. Thus, tall, lean slalom skiers performing on smooth, narrow skis are presented with extraordinary stability challenges, even before encountering wind-, wave-, and boat-imposed forces.

The mechanisms underlying postural control during balance perturbations are extremely complex and arise from the collective functioning of the somatosensory, visual, and vestibular systems (4, 66). These systems all provide sensory input regarding body position to the central nervous system, which then integrates it and activates an appropriate motor response. Motor responses to postural disturbances are generally classified as "fixed-support" or "change-insupport" strategies (66), depending on whether or not the BOS is altered. The major fixed-support responses are the ankle strategy and the hip strategy, which involve activating ankle and hip joint musculature, respectively, to reposition the COM over the BOS (13, 63). The ankle strategy dominates in correcting minor postural disturbances, whereas the hip strategy takes over when postural disturbances are more severe, when ankle motion is limited, or when unstable surfaces reduce the effectiveness of the ankle strategy. Change-in-support strategies include stepping in the direction of the displaced COM to move the BOS under it and making grasping movements with the limbs to offset destabilizing shifts in the COM (13, 52, 63, 66). When these strategies fail to correct balance, falls occur.

The value of understanding the major postural control mechanisms lies in providing insight into the importance of the hip and trunk musculature to stabilizing posture in slalom water skiers. Contributions by the ankle strategy are limited by the unstable sport surface and modern, high-wrap bindings that now dominate the slalom ski industry, and contributions by the stepping and grasping strategies are precluded by the fixed foot position and the need to maintain firm rope tension. Thus, the hip strategy must bear the major responsibility for maintaining balance. To enhance its effectiveness, skiers should regularly perform some conditioning exercises using a tandem stance, as on their skis, and should strive to minimize stepping and grasping movements. As stance width decreases, body movements more easily shift the COM outside the BOS and increase postural sway (45, 93). Increased sway, in turn, intensifies stabilizing mechanisms, including muscle and joint proprioception. Therefore, purposefully narrowing the stance during conditioning exercises can specifically help train better balance.

Many exercises, such as squats, can be modified to incorporate the tandem stance and thereby more specifically impose the demands of slalom water skiing. Several authors (10, 39, 43) already have recognized the value of performing squats and other conditioning exercises with a split stance to enhance training specificity. Because many athletes perform skills using a staggered, rather than a parallel, stance (e.g., running, jumping, throwing), it makes sense for their training to incorporate this position. Likewise, because slalom skiers perform exclusively in the tandem position, their conditioning should reflect this unique motor demand. The tandem squat also may benefit slalom skiers through its nature as a closed-chain exercise. Closedchain exercises are known to impose less joint shear stress and to stimulate greater motor unit activation, muscle cocontraction, joint congruency, and proprioception than do open-chain exercises (47, 48, 85, 90)—factors all conducive to enhancing postural control and reducing risks of injury (18, 38, 49, 57, 77).

Metabolic Analysis

Metabolically, slalom water skiing is somewhat difficult to characterize. A cursory assessment of the high-intensity muscular efforts, rapid accelerations, and short duration of a single slalom pass might suggest its classification as a pure power sport. However, closer inspection reveals that some of its movements are explosive (e.g., pull and backward lean just prior to wake crossing), whereas some are relatively static (e.g., knee flexion and back extension). Moreover, its intensity, duration, and considerable static activity (during which muscle blood flow is restricted) make it heavily reliant on the phosphagens (ATP-PCr) and anaerobic glycolysis for energy, yet it also appears, for several reasons, to depend significantly on aerobic metabolism. First, in high-intensity running events of similar duration to a single slalom pass (e.g., 200-m sprint), aerobic contributions have been reported to be as high as 28–33% (19, 78). Second, many skiers train multiple passes consecutively, imposing continuous work for 3–4 minutes and extending into the aerobic realm of the energy continuum. Third, the sheer proportion of muscle mass recruited during slalom skiing may activate central cardiovascular command mechanisms and thereby raise aerobic energy contributions. Cardiorespiratory responses to exercise are regulated by anumber of factors, including peripheral reflex activity within the working muscles (57, 70) and central command (30, 71). Though the mechanisms underlying these responses are beyond the scope of this paper, response strength is related directly to active muscle mass and exercise intensity (24, 92). In simple terms, the more muscle involved in an activity and the higher the intensity at which it works, the greater the stimulation of heart rate, blood pressure, myocardial contractility, and cardiac output. In summary, though a high aerobic capacity is not necessary to excel at slalom water skiing, neither is pure explosive power.

Additional support for significant aerobic contributions to slalom water skiing is provided by investigations of its Alpine counterpart. Though there are obvious, fundamental differences between downhill slalom skiing and slalom water skiing, there are also clear similarities in both technique and athlete profiles. Movement patterns in both types of slalom skiing involve similar body inclination, counterrotation, edge changing, and speed, and athletes in both disciplines tend to be tall, lean, strong in the same muscle groups, and possessing of moderately high aerobic capacities (1, 46, 47, 54, 60). Several reports on Alpine skiing recognize the dominance of anaerobic metabolism but also the significance of aerobic metabolism. Veicsteinas et al. (87) reported the anaerobic:aerobic energy contributions to Alpine slalom skiing to be approximately 60%:40%. White and Johnson (90) found that anaerobic exercise tests were better than aerobic tests at predicting performance in competitive skiers, but that skiers nevertheless had above-average aerobic capacities (11). Other groups also have shown Alpine slalom skiers to have above-average aerobic power (14, 72, 83), high proportions of slow-twitch muscle fibers (72, 89), and selective reduction in muscle glycogen from type I versus type II fibers following ski training (84, 89).

At present, no studies have directly measured the energy demands of slalom water skiing. Two have reported moderate-to-high levels of both anaerobic and aerobic power among elite water skiers (46, 47), but, as cross-sectional studies, cannot distinguish whether sport-specific training or natural selection explain the characteristics. With continuing advancements in portable metabolic systems, direct measurements of oxygen consumption during water skiing may soon be feasible. Until then, indirect insights into the sport's metabolic requirements seem to indicate that elite performance is not limited to either the genetically elite anaerobic or aerobic athlete.

Injury Analysis

Unfortunately, there is little documentation of the common sites, incidences, and mechanisms of injury among skilled slalom water skiers. Several reports identify a vast array of injuries sustained during water skiing, ranging from minor strains to catastrophic propeller injuries (5, 32, 33, 36, 37, 64, 68, 75, 80). However, these reports neither adequately distinguish trends among the sport's different subdisciplines (slalom, trick, jumping, and barefooting) nor delineate contributions from fatigue, equipment, driver skill, or other miscellaneous factors (e.g., alcohol or drug use by skiers or drivers, interference from birds, fish, or submerged objects). Moreover, they draw different conclusions as to the frequency and severity of injuries among skilled versus novice skiers. Skilled skiers' risks likely are reduced by experience, better ski conditions, and greater fitness but are increased by faster skiing speeds and more highly competitive situations. Future research should seek to clarify these ambiguities.

Table 1
Water skiing Injuries

Sites of injury	%	Lower extremity injury sites	%	Types of injury	%
Lower extremity	34.0	Knee	30.8	Strain or sprain	36.3
Trunk	27.1	Thigh	25.7	Contusion or abrasion	17.1
Face	20.8	Foot	14.7	Laceration	17.1
Upper extremity	13.0	Lower leg	13.9	Fracture	9.0
Head	4.3	Ankle	13.4	Traumatic brain injury	2.4
Other	0.9	Toe	1.5	Other	18.5

Data are from Hostetler et al. (36).

The best characterization of water skiing injuries to date is the report of Hostetler et al. (36), which describes water skiing (n = 517) and wakeboarding (n = 95) injuries sustained in the United States between January 1, 2001, and December 31, 2003. Data extracted from the National Electronic Injury Surveillance System show that among skiers, both the types and sites of injuries were distributed broadly, as shown in Table 1. The lower extremity was the most commonly injured body region (34% of all injuries), whereas sprain or strain was the most common diagnosis (36.3% of all injuries). Within the lower extremity, specific injury sites were distributed widely, though injuries to the knee and thigh accounted for more than half of all injuries to this region (56.5%).

Consistent with the findings of Hostetler et al. (36) is the high prevalence of acute hamstring trauma among published case reports of water skiing injuries (12, 15, 51, 75, 88). Hamstring strains, ruptures, and avulsions seem to afflict both novice and skilled skiers, generally as a result of a forward fall in which the knees extend and hips hyperflex. Preexisting pathology and weakness have not been deemed contributing factors, and thus these injuries may not be preventable. Nevertheless, skiers' hamstrings:quadriceps strength ratios should be assessed to ensure that they meet minimum recommendations. Optimum ratios are thought to vary for different types and speeds of athletic movements, but a ratio of at least 0.5 has been recommended to reduce risks of hamstring injury (25). Because slalom skiing constantly loads the quadriceps, skiers may need to place greater emphasis on hamstring strengthening to achieve and maintain better proportionality.

Disproportionate training also may be warranted for other muscle groups to prevent the development of muscular imbalances that could predispose to injury, especially during the ski season. As for the quadriceps, slalom skiing constantly loads the back extensors and forearm flexors and may warrant compensatory training of the abdominal, chest, and forearm extensor muscles. This recommendation is supported by data showing professional water skiers to have significantly stronger upper back musculature than untrained controls have, but similar chest strength, suggesting training-induced muscular imbalances (46).

Another study of potential relevance to injury prevention is that of Keverline et al. (44). This group measured force transmission through the upper body during the deepwater slalom start, as a means of estimating stress levels chronically imposed on skiers' arms and shoulders. A load cell incorporated into a towrope assembly showed a mean relative force of 2.0 ± 0.5 times body weight as skiers were pulled from partial submersion to stable planing on the water. The authors concluded that such high forces could contribute to, or exacerbate, existing upper extremity pathology—a conclusion supported by anecdotal reports from skiers with chronic shoulder problems.

Analysis of the published data, biomechanical requirements, and anecdotal information from athletes suggest that the lower extremity, back, and shoulders are the body regions most susceptible to injury during slalom water skiing. However, because the unpredictable nature of falls makes it possible to injure any area, sound prehabilitation programs will address all major muscle groups, as well as individual weaknesses and imbalances.

Sport-Specific Exercises

Tandem Squat (Figure 5)

To perform the tandem squat, position the body, with dumbbells or a barbell, as for a basic back squat (dumbbells at the sides or barbell resting on the upper back, chin up, eyes focused straight ahead or slightly upward, shoulders retracted). However, instead of assuming a wide, parallel stance, stand with the feet in tandem. It may be helpful to place the feet on a line on the floor or a seam in

Figure 5. The tandem squat.

the matting. Slowly flex the knees, hips, and ankles to descend in a controlled fashion, while simultaneously squeezing the knees together. Concentrate on minimizing sway. Strive to descend until the rear thigh is parallel to the floor, while keeping the body weight evenly distributed between the feet, the feet flat on the floor, and the knees from moving beyond the toes. Return to the fully upright starting position and repeat for the desired number of repetitions. Although skiers do not alternate foot position on the ski, this exercise should be trained with both the right and left leg leading to promote balanced strength and proprioceptive function.

Athletes first should attempt this squat modification without added resistance. Once a target number of repetitions can be performed with minimal sway and without stepping, progression may be made to squatting with dumbbells or a barbell. As an intermediate step to develop confidence in the technique, individuals may perform the exercise using a Smith machine. However, because Smith machines essentially remove the proprioceptive challenge of the exercise, progression to free weights should be made as soon as possible. The dumbbell squat is recommended as the primary version, because dumbbells exert independent forces on the upper limbs, just as the towrope does at times during slalom skiing.

Some athletes may find it difficult to keep the knees, particularly the rear knee, from moving slightly beyond the toes when performing this exercise—a common contraindication because of its association with high shear forces at the knee joint (3). Though increased shearing is clearly undesirable and individual flexibility deficits should be addressed, some evidence suggests that restricting forward movement of the knees while squatting may simply increase force application to the hips and back (26), thereby raising the injury potential. Thus, forward movement of the knees should be minimized, but a small amount may be acceptable and is likely to occur at times during slalom skiing.

Tandem Deadlifts (Figure 6) The stiff-legged deadlift—excellent for strengthening the entire posterior chain—is another exercise well suited to incorporating the balance challenge of the tandem stance. It is particularly valuable for training the ability to recover from being pulled forward while skiing. However, it is a high-risk exercise, due to the length of the lever arm between the resistive force and joint axis of rotation (27, 65). The long lever places the back muscles at a mechanical disadvantage and requires them to produce forces greater than the loads actually being lifted. Only athletes free from hip and spine pathology, cognizant of proper technique, and possessing of adequate strength and flexibility in the hamstring and lumbar regions should attempt this exercise.

To perform tandem deadlifts, position the body, with dumbbells or a barbell, as for the traditional stiff-legged deadlifts (chin up, eyes focused straight ahead or slightly upward, shoulders retracted, lower back flat or slightly arched, hands directly below the shoulders, knees slightly bent) but place one foot directly in front of the other. Keeping the dumbbells or barbell very close to the legs throughout the movement, slowly flex the hips until the hands approach the tops of the shoes, the movement is limited by hamstring tension, or the back begins to round (27, 65). Slowly reverse the movement to stand fully erect, then repeat.

Figure 6. The tandem deadlift.

Figure 7. The supine plank.

Supine Plank (Figure 7) The supine plank exercise is adapted from the supine plank test used in diagnosing high hamstring tendinopathy (25). When included in a comprehensive training program, this exercise may help improve muscular strength, endurance, proprioception, and injury resistance throughout the entire posterior chain. To perform the supine plank, lie supine, with the elbows directly under the shoulders and forearms on the ground, parallel to the torso. Lift one foot and place it in tandem above the other. Raise the pelvis so that the body weight is supported entirely by the forearms and single heel. Hold for 5–10 seconds, then switch feet, without lowering the pelvis. Take care to avoid breathholding during the exercise. Complete sets of 10–20 alternating repetitions (5–10 repetitions per leg). Sets also may be completed by performing 5–10 consecutive repetitions on a single leg, by raising the pelvis, holding for the desired count, lowering momentarily to the rest position, and repeating.

Despite its simple appearance, the supine plank is an intense exercise and it is important that a proper warm-up precede it. It is recommended that its progression entail increasing repetition duration and/or number, rather than loading the torso with additional weight. Current research indicates that muscular endurance of the trunk extensors bears a much stronger relationship with back health than with muscular strength (56).

Prone plank

The prone plank is essentially the mirror image of the supine plank, performed facing the floor (25). It requires coactivation of the quadriceps, hamstrings, gluteals, back extensors, abdominals, latissimus dorsi, and pectoral muscles to maintain a steady, hollowed body position. To perform the prone plank, lie face down, with the head and chest propped up by the forearms. Lift one foot and place it in a tandem position above the other. Raise the body off the ground to fully support it on the forearms and ball of one foot, maintaining a straight body line from head to foot. Hold the position for several seconds, then lower under control to the rest position. Avoid breath-holding during the exercise and perform 2–3 sets, alternating support legs. Progression for this exercise should entail increasing duration of the hold.

Side Bridge

According to McGill (56), the isometric side bridge is an effective exercise for training the quadratus lumborum and abdominal obliques. Because these muscles are important to the reach phase of the slalom turn, this exercise is an excellent addition to the water skier's training program. It can be performed in several progressions, from basic to advanced. To perform the basic side bridge, lie on one side, with head and chest propped up over the forearm. The forearm should be perpendicular to the torso and elbow directly under the shoulder, flexed to 90°. The iliac crests should be aligned vertically and the knees also flexed to 90°. Viewed from above, the body should form a straight line from head to knee. Raise the hips off the ground to form a straight body line when viewed from the front, hold the position for several seconds, then lower under control to the rest position. Over time, increase the duration of the hold, remembering to breathe normally throughout. Perform 2–3 sets, alternating sides.

To perform the intermediate version, position the body as for the basic side bridge but extend the knees and move the top foot into a tandem position in front of the other. To perform the advanced version, position the lower body as for the intermediate version but use the hand, rather than the forearm, to support the upper body (Figure 8). Once the advanced side bridge can be performed with minimal sway for the desired amount of time, athletes can practice alternately rolling from support on one hand to support on the other, reestablishing stability as quickly as possible (rolling side bridge) (56). This enhances the ability to steady the body after repositioning the COM, as is necessary during ski edge changing.

Figure 8. The advanced side bridge.

Torso Rotations

Various cable, resistance band, and medicine ball exercises that strengthen the torso with a rotational element may benefit water skiers by increasing power during the slalom pull and counterrotation. Several cable "chop" exercises have been recommended previously for enhancing multiplanar, functional strength for other sports (16, 22, 23) and are well suited to skiers. To perform oblique cable chops, stand facing away from a cable system, at an approximate 45° degree angle, with the feet shoulder-width apart (though this exercise also can be performed from a tandem stance). Grasp the handle (set at about shoulder level) with both hands, and pull diagonally toward one hip, as during a pull toward a slalom buoy. It has been recommended that cable chops be performed with loads that permit no fewer than 8–10 repetitions, due to their large arc of motion (16).

Wall Slides / Dock Slides

Because falls during slalom skiing can impose tremendous impact and distraction forces on the arms and shoulders, it is critical for the scapular musculature to provide as strong a base of support as possible for the upper extremity. Two simple exercises for conditioning the scapular stabilizers can be performed either standing against a wall (34) or lying on the ground. To strengthen the external rotators, stand back to a wall or lie supine on the ground. Raise the arms overhead and press the scapulae and backs of the arms and hands firmly against the wall or ground. Slowly slide the arms and hands down the wall (like performing a lat pull-down) or along the ground (like making a snow angel) while continuing to maintain as much contact and pressure as possible. Once the upper arms reach the sides, reverse the motion. Carry out 2–3 sets of 10–15 repetitions.

To target the internal rotators, stand facing a wall or lie prone on the ground. Repeat the motion of the external rotation exercise, pressing the anterior surfaces of the arms and hands against the wall or ground. Carry out 2–3 sets of 10–15 repetitions.

Other Slalom-Specific Exercises and General Conditioning

Several traditional resistance training exercises also can be modified for slalom ski training by incorporating an alternated grip, as is used in holding the towrope handle. Seated rows and pullups are good examples. An added benefit of this modification is that its novelty can enhance motivation and enjoyment and thereby indirectly contribute to muscular development.

Additional Considerations for Training and Injury Prevention

The importance of warm-up exercise cannot be overstated for slalom water skiers. A proper warm-up increases blood flow to working muscles, which in turn enhances nutrient supply, tissue oxygenation, and waste removal (9, 21). It facilitates motor unit recruitment, which directly affects the rate and force of muscle contractions (7, 67, 81), and may prolong time to fatigue (31). It raises muscle and core body temperature, promoting oxygen-hemoglobin dissociation at the tissues, faster nerve impulse conduction, and increased joint range of motion (9, 42, 82). Warmup also is believed to help athletes mentally prepare for their events, possibly by influencing arousal and focusing attention (2, 8, 95). In summary, through several mechanisms, a proper warm-up may enhance muscular coordination, strength, power, reaction time, flexibility, and concentration (9, 28, 73, 74, 77).

Unfortunately, many water skiers move from sedentary roles as spotters and boat drivers to intense sport activity without warming up at all, let alone warming up to support peak athleticism. Skiers who omit a proper warm-up may not only relinquish performance benefits, but suffer outright decrements when cold water, cold air, and wind exposure move the body further from the warmed state. Many factors influence the degree to which cold exposure affects individuals, including water and air temperature, duration of exposure, water turbulence and wind speed, body fat and surface-to-mass ratio, metabolic rate, and presence or absence of insulative clothing (61, 85, 94), but even environmental temperatures only slightly below body temperature (36–37°C, 96.8–98.6°F) will cause heat loss from bare-skinned individuals. Heat loss, in turn, will initiate multiple thermoregulatory responses aimed at preserving core temperature. These responses help protect against cold injury but may interfere profoundly with physical performance; they are especially exaggerated in cold water, where rates of heat transfer may be 25 times greater than in air of the same temperature (59).

The body's initial defense against heat loss is to cause widespread vasoconstriction in the extremities (85). Peripheral vasoconstriction shunts blood toward the body's core, thereby limiting its release of heat at the body surface. Although this helps preserve core temperature, it also reduces blood flow to the working muscles, reducing their temperature, extensibility, and nerve conduction velocity. These effects may significantly diminish strength, power, speed, reaction time, dexterity, tactile sensitivity, and postural control (17, 29, 35, 53), all of which could alter the outcome of a slalom pass.

Secondary defenses against heat loss include voluntary and involuntary muscular action—physical activity and shivering (61, 85). Ironically, both increase metabolic heat production, but also undermine heat retention, by inducing muscular vasodilation and sabotaging the effectiveness of peripheral vasoconstriction. Physical activity also increases convective heat loss, because limb movements accelerate the flow of water and air over the body surface. Thus, if preservation of core temperature becomes the body's priority, restricted muscle blood flow may impair performance. If continuing to perform becomes priority, core body temperature may drop and its associated anesthetic effects (35) may limit performance.

Cold exposure also may increase skiers' susceptibility to musculoskeletal injury. Cold water immersion reduces the extensibility of soft tissues (35, 94)—an adverse effect for any skier who falls and inadvertently forces a joint through an unaccustomed range of motion. Because warming reduces muscle stiffness (62, 69) and allows greater lengthening before failure (73), a proper warm-up is strongly recommended to help reduce risks of injury. Of course, to prevent undermining the positive effects of a proper warm-up, cold exposure should be limited to reasonable time frames and insulative clothing should be worn when appropriate. Wet suits and dry suits preserve body heat by reducing convective heat loss and should be worn when cold stress is severe enough to elicit shivering and numbness. Many skiers complain about the added bulk of these suits, but any movement resistance they impose is likely to be less detrimental to performance than significant cold stress would be. Further research should address the effects of insulative clothing on motor performance.

An ideal warm-up for short-term, highintensity events, such as slalom water skiing, should be of an intensity and duration sufficient to raise muscle temperature and baseline oxygen consumption, but not to cause significant fatigue, lactate accumulation, or depletion of high-energy phosphates immediately prior to performance (9). In general, some form of aerobic activity should be carried out for 5–10 minutes, followed by several minutes of sport-specific exercises and stretches, targeting the prime movers of the athletic task to be performed. Precise specifications will depend on the task, the fitness profile of the individual, the environmental conditions, and any constraints imposed by the location, organization, or rules of the event. For many slalom skiers, location constraints impose the greatest barrier to achieving a proper warm-up. Skiers who wait their turns to ski on a dock or in a boathouse can warm-up as recommended, but skiers who wait their turns seated in a boat are presented with a greater challenge. Such skiers are advised to perform multiple, complex exercises, such as squats, lunges (forward, lateral), push-ups, "supermans," curl-ups, leg kicks (forward, backward, lateral), and marching to raise muscle temperature and oxygen consumption as much as possible.

Conclusion

Slalom water skiing is an extremely demanding technical event, requiring a unique blend of strength, power, endurance, timing, coordination, and balance. For individuals seeking to realize their skiing potential, dryland conditioning must be considered essential. Attempting to ski into shape can both slow progress and increase susceptibility to injury. Dryland training should be used to prehabilitate injury-prone muscles and joints, to enhance on-the-water training, to correct muscular imbalances arising from skiing, and to minimize losses of neuromuscular adaptations during the off-season. A variety of modifications to traditional exercises can enhance both specificity of training and motivation to condition. ♦

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